

How does academic achievement relate to cardiorespiratory fitness, self-reported physical activity and objectively reported physical activity: a systematic review in children and adolescents aged 6–18 years

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Accepted 12 September 2017

ABSTRACT

Objective This report aimed to systematically review the evidence for a differential association between objective and self-reported physical activity and cardiorespiratory fitness on academic achievement.

Design Systematic review.

Data sources Studies were identified from searches in Embase, Education Resources Information Center, PubMed, PsycINFO, SPORTdiscus and Web of Science databases from January 2000 to December 2016.

Eligibility criteria for selecting studies Eligibility criteria included cross-sectional, longitudinal and interventional study designs. Outcomes included students' school grade or a standardised test or measure of academic achievement. Explanatory variables were cardiorespiratory fitness and objective and self-reported physical activity. Inclusion criteria included school-aged children and adolescents aged–18 years (or students from primary to secondary school when student's participants age was not described) and articles published in English, Portuguese or Spanish.

Results A total of 51 articles met inclusion criteria: 41 cross-sectional, 2 intervention and 8 longitudinal studies. Results from 11 studies were inconsistent regarding the relationship between objectively measured physical activity and academic achievement. Ten of the 16 articles reported positive associations between self-reported physical activity and academic achievement. From the 22 studies that analysed the relationship between cardiorespiratory fitness and academic achievement, it was verified that they all generally support the beneficial effect of cardiorespiratory fitness on students' academic achievement.

Conclusion Higher cardiorespiratory fitness may be important to enhance children and adolescents' health and, additionally, academic achievement. Due to a lack of consensus across studies, methodological issues associated with the assessment of physical activity should be considered when investigating physical activity and academic achievement.

INTRODUCTION

Physical activity and cardiorespiratory fitness are associated with a variety of health benefits in children and adolescents.^{1–3} In addition to the benefits on physical and mental health, studies in neuroscience have shown that physical activity

and cardiorespiratory fitness are related to brain structure and function.⁴ The pathways by which they may change brain structure and function include: (1) alterations in thickness of grey matter in specific cortical regions⁵ and integrity of white matter tracts that support executive function⁶; (2) alterations in brain plasticity that change the structure of the neuron and strengthen its signalling capability^{7,8}; and (3) improvements in attention,⁹ memory^{10,11} and executive function.¹² Accordingly, it is expected that the benefits of cardiorespiratory fitness and physical activity on brain structure, function, plasticity and cognition might translate to improvement in academic achievement.⁵

There is a growing body of literature that has examined the relationship between physical activity and cardiorespiratory fitness with academic achievement in children and adolescents.^{13–15} Although most studies have shown that physical activity and cardiorespiratory fitness are associated with enhanced academic achievement,^{13,14} the literature has not yet reached consensus,¹⁵ as there are some studies showing no associations^{16,17} or negative associations^{18,19} between physical activity or cardiorespiratory fitness with academic achievement.

These inconsistent results may occur since physical activity can be assessed objectively or subjectively and, moreover, physical activity and cardiorespiratory fitness may not have the same relation to academic achievement. In fact, self-reported measures tend to overestimate physical activity when compared with accelerometry.^{20,21} Furthermore, mean time spent per day in moderate-to-vigorous physical activity (MVPA) can differ by over 100 min when comparing questionnaires and accelerometers (146 min/day using a questionnaire vs 24 min/day using an accelerometer).²¹ Thus, separating investigations of objectively measured and self-reported physical activity and cardiorespiratory fitness would help to clarify the associations between physical activity and cardiorespiratory fitness with academic achievement. We aimed to systematically review the evidence from 2000 to 2016 of an association between objective and self-reported physical activity and cardiorespiratory fitness with academic achievement in school-aged children and adolescents.



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To cite: Marques A, Santos DA, Hillman CH, et al. *Br J Sports Med* Published Online First: [please include Day Month Year]. doi:10.1136/bjsports-2016-097361

METHODS

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines²² and the association of physical activity and academic achievement protocol for systematic reviews and meta-analysis.²³ The protocol was registered on the International Prospective Register of Systematic Reviews database under the number CRD42016043204.

Inclusion criteria

Primary source articles published from 2000 to 2016 in peer-reviewed journals were eligible for inclusion if data were presented on the relationship among physical activity, cardiorespiratory fitness and academic achievement. Specific eligibility criteria included the following: (1) cross-sectional, longitudinal and interventional study designs (study design criterion); (2) outcomes included students' school grade or a standardised test or measure of academic achievement (outcome measure criterion); (3) cardiorespiratory fitness, objective and self-reported physical activity and academic achievement (relationship criterion); (4) school-aged children and adolescents aged 6–18 years, or students from primary, elementary and secondary school when participants' age was not reported (participants criterion); (5) articles published in English, Portuguese or Spanish (language criterion); (6) articles were excluded if they did not meet inclusion criteria or did not include findings related to the inclusion criteria (ie, measured cardiorespiratory fitness and physical activity but failed to compare with academic achievement) (exclusion criteria); and (7) studies with a sample size below 30 ($n < 30$) were also excluded,²⁴ because the measure of physical activity (subjective and objective) in small samples is subject to a greater variability.

Search strategy and study selection

Studies were comprehensively identified by searching in electronic databases of peer-reviewed articles published from January 2000 to December 2016. The last search was conducted on 17 January 2017. The search was applied to Embase, Education Resources Information Center, PubMed, PsycINFO, SPORTdiscus and Web of Science. Investigations using accelerometers started to rise in the beginning of the millennium.²⁵ To avoid any secular trends in the outcomes and explanatory variables (eg, subjective vs objective outcomes), the selection criteria was restricted to studies published since 2000, ensuring that all independent variables were analysed within the same time frame.

Search terms were defined through discussion among the research team and were used in each database to identify potential articles with abstracts for review. The search terms were as follows: 'physical activity' OR 'physical education' OR 'sport' OR 'athletic participation' OR 'exercise' OR 'fitness' OR 'aerobic' AND 'academic achievement' OR 'academic performance' OR 'academic attainment' OR 'academic skills' OR 'academic ability' OR 'performance at school' OR 'cognitive performance'.

Retrieved titles and abstracts were independently assessed for eligibility for inclusion in the review by two authors (AM and DAS) and coded as 'yes', 'no' or 'maybe'. Duplicate entries were manually removed. Relevant articles were then retrieved for complete review and analysis. The same two authors reviewed the full text of potential studies, and decisions to include or exclude studies in the review were made by

consensus. A Microsoft Excel spread sheet was developed to track eligibility status. Authors of articles lacking information were contacted for clarification.

Data extraction and harmonisation

A data extraction form was developed based on the PRISMA statement.²² Relevant data were extracted from each manuscript by one author (AM), and coding was verified by the other authors (DAS and LBS). Disagreements were resolved by discussion among authors. Data extracted from each article included study information (design, country, sample size, groups compared and cardiorespiratory and/or physical activity groups/interventions), participant characteristics (age, sex and school grade), cardiorespiratory fitness and physical activity assessment method, academic achievement assessment method and results.

Study quality and risk of bias

Study quality was assessed using checklist criteria from the Quality Assessment Tool for Quantitative Studies.²⁶ The checklist was adapted to evaluate both experimental and observational studies. The checklist comprises 19 items, assessing eight key methodological domains (sections): selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity and analyses. Each section was classified as strong, moderate and weak methodological quality. Then, a global rating is determined based on the scores of each component. Two researchers rated the articles in each domain and in overall quality. Discrepancies were resolved by consensus. Studies were not excluded based on methodological quality.

Synthesis of results

This systematic review analysed the relationship between objectively measured and self-reported physical activity, cardiorespiratory fitness and academic achievement in children and adolescents. Although academic achievement was measured through school grades or standardised test scores, the articles were not grouped by the outcome variable. However, since inconsistent study results may be due to the fact that physical activity can be assessed objectively or subjectively and that physical activity and cardiorespiratory fitness may not have the same effect on academic achievement, articles were grouped by the exposure variable (cardiorespiratory fitness, objectively assessed physical activity and subjectively assessed physical activity).

Considerable heterogeneity existed across studies for several parameters. These parameters included the following: participant characteristics, academic achievement measures and cardiorespiratory and physical activity assessment methods. The details for each study, including design, measures, participant characteristics and sample size, study quality and results, are presented in a consistent manner.

RESULTS

Literature search

The flow of citation through the systematic review process is depicted in [figure 1](#). The systematic literature search yielded a total of 778 potentially relevant publications. After excluding duplicates ($n=463$), 315 publications were screened for inclusion in the review, and a total of 218 articles were rejected at title and abstract level. Consequently, 97 potentially relevant citations were obtained, of which 51 articles were identified as relevant.

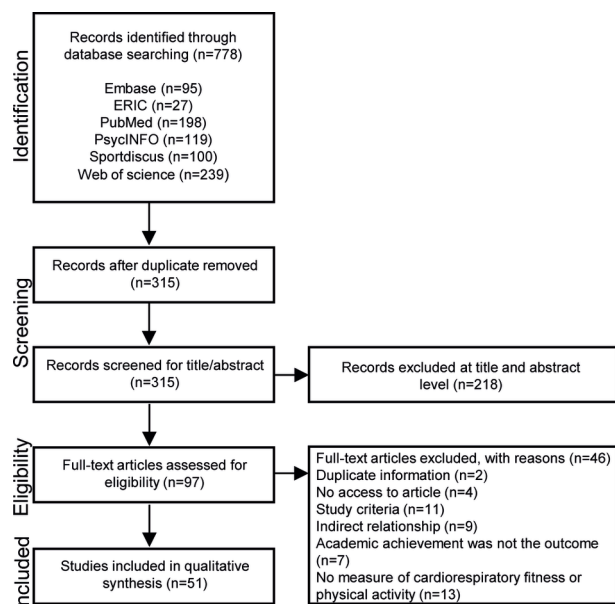


Figure 1 ERIC, Education Resources Information Center.

Study characteristics

The study characteristics are summarised in [table 1](#). Of the 51 included studies, 41 were cross-sectional, 2 intervention and 8 longitudinal. In half of the studies, the outcome variable (academic achievement) was the students' marks at the school level, and standardised tests were used for the other half. Most studies analysed the relationship between academic achievement with cardiorespiratory fitness, followed by the relationship with self-reported physical activity and lastly objectively measured physical activity. Five studies used both cardiorespiratory fitness and objective physical activity as independent variables, and one study used cardiorespiratory fitness and self-reported physical activity. Most studies took place in Europe (n=20) or North America (n=17), and the remainder studies were from Africa (n=1), Asia (n=5), Oceania (n=2) and South America (n=6). Three studies were considered to be of weak methodological quality, 14 of moderate quality and the other 34 of strong quality.

Principal findings

Objectively measured physical activity and academic achievement

The description of the studies reporting the relationship between objectively measured physical activity and academic achievement is presented in [table 2](#). The results from the 11 studies that were screened^{17 19 27–35} were inconsistent regarding the relationship between objectively measured physical activity and academic achievement. Four studies of strong quality provided partial support for a positive relationship.^{27 28 31 35} Vigorous physical activity (VPA) was associated with academic achievement in girls, after controlling for confounding factors, but no significant association was observed in boys.²⁸ In a longitudinal study, the percentage of time spent in MVPA predicted greater performance in English assessments across sexes but not in math and science.²⁷ Higher MVPA was related to higher academic achievement in writing and numeracy but not in reading and spelling.³¹ In an intervention study, there was a significant effect of physical activity on numeracy among the children who initially performed the most poorly on the test, but no significant effect of the intervention on academic achievement measures was observed using intention-to-treat analyses.³⁵ These studies that partially supported a positive relationship between objectively measured

Table 1 Characteristics of the studies examining potential relationship between CRF, PA and academic achievement

Characteristics	Number of studies
Study design	
Cross-sectional	41
Intervention	2
Longitudinal	8
Outcome measured	
School grade*	25
Standardised tests	26
Independent variable	
Only CRF	23
Only PA objective	9
Only PA self-reported	13
CRF and PA objective	1
CRF and PA self-reported	5
Sample characteristics	
Country	
Australia	2
Brazil	2
Canada	1
Chile	3
China/Taiwan	3
Denmark	1
Finland	4
Germany	1
Iceland	1
Iran	1
Netherlands	2
Norway	1
Portugal	2
South Africa	1
South Korea	1
Spain	4
Sweden	1
UK	3
USA	16
Sex	
Only boys	1
Boys and girls	50
Age group	
≤10 years	9
>10 years	34
≤10 and <10 years	8
Study quality	
Weak	3
Moderate	14
Strong	34

*School grades were recorded from school records.
CRF, cardiorespiratory fitness; PA, physical activity.

physical activity and academic achievement were performed in different countries, with sample sizes ranging from 232 to 4755 children and adolescents. In one study of strong quality and with a large sample, physical activity was negatively associated with all academic achievement indicators after adjusting for potential confounders, such as adiposity and fitness.¹⁹ However, the strength of the association was weak in all activity intensities. In the other six studies, no significant association was found between physical activity and academic achievement.^{17 29 30 32–34}

Review

Table 2 Description of the studies reporting the relationship between objectively measured PA and AA in children and adolescents

Source and study quality	Study design and sample characteristics (country, age range/mean, grade, sex, n)	Outcome measured	PA measure	Adjustments for confounders	Main results
Kwak <i>et al</i> ^{28†}	Cross-sectional Sweden, 16 y, grade 9, boys and girls, n=232	School grades	Accelerometer	Age, pubertal phase, sum of skinfolds, mother's education, family structure and parental monitoring.	VPA was associated with AA in girls, after controlling for confounding factors.‡ LPA and MPA were not associated with AA in boys. (±) LPA, MPA and VPA were not associated with AA in boys.§
LeBlanc <i>et al</i> ^{30†}	Cross-sectional USA, 10.5 y, grades 4–6, boys and girls, n=261	Standardised annual test	Accelerometer	Age, sex and SES.	MPA was not associated with AA.§
Booth <i>et al</i> ^{27†}	Longitudinal UK, 11 y, boys and girls, n=4755	Compulsory nationally administered tests	Accelerometer	Age, birth weight, gestation, age of mother at delivery, mother's oily fish intake, mother smoking habits in the first 3 months of pregnancy, BMI Z score, pubertal stage, ethnicity, maternal educational, occupational social class and total PA.	%MVPA at 11 y predicted performance in English assessments at 11, 13 and 16 y, in boys and girls.‡ %MVPA at 11 y predicted performance in maths and sciences assessments at 16 y, in girls.‡ %MVPA at 11 y was not associated with performance in sciences and maths at 11, 13, and 16 y, in boys.§ %MVPA at 11 y was not associated with performance in sciences and maths at 11 and 13 y, in girls.§
Lambourne <i>et al</i> ^{29†}	Cross-sectional USA, 7.6 y, grades 2–3, boys and girls, n=401	Weschler Individual Achievement Test—Third Edition	Accelerometer	Sex, grade, BMI, mother's education level and household income.	Total PA was associated with math achievement (partially mediated by fitness).‡ Total PA was not associated with reading or spelling.§
Syväoja <i>et al</i> ^{33†}	Cross-sectional Finland, 12.2 y, grades 5–6, boys and girls, n=277	School grades	Accelerometer	Sex, children's learning difficulties, highest level of parental education and amount of sleep.	MVPA was not associated with grade point average.§
Esteban-Corbejo <i>et al</i> ^{19†}	Cross-sectional Spain, 10.5 y, boys and girls, n=1778	School grades	Accelerometer	Sex, age, city, maternal education, birth weight, gestational age, BMI and z-score values computed from CRF and motor fitness tests.	MPA, VPA and MVPA were inversely associated with all AA indicators.¶
Hansen <i>et al</i> ^{17†}	Cross-sectional USA, 7.8 y, 2–3 boys and girls, n=687	Standardised composite academic test	Accelerometer	Sex, grade, race, ethnicity, mother's education level, household income and BMI.	Total PA was not significantly correlated with AA, either linearly or non-linearly.§
Van Dijk <i>et al</i> ^{24†}	Cross-sectional Netherlands, 13 y, grades 7–9, boys and girls, n=255	School grades	Accelerometer	Sex, nationality, grade, school level, SES, BMI, CRF, pubertal phase, depressive symptoms and self-esteem.	Considering the overall sample, weekly volume of total PA and MVPA was not associated with AA.§ In grade 7 students, weekly volume of total PA and MVPA were negatively associated with AA, and MVPA was also negatively associated with mathematics achievement.¶ In grade 9, weekly volume of total PA and MVPA were positively associated with maths performance.‡
Maher <i>et al</i> ^{31†}	Cross-sectional Australia, 10.2 y, grade 5, boys and girls, n=285	National Assessment Program – Literacy and Numeracy	Accelerometer	Sex, school clustering, MVPA, sedentary behaviour, BMI z-score, ethnicity, highest household education, household income, marital status, mothers employment hours and number of siblings.	Higher MVPA was related with higher AA in writing and numeracy.‡ MVPA was not related to language, reading and spelling.§
Pindus <i>et al</i> ^{22†}	Cross-sectional UK, 8.7 y, boys and girls, n=74	Kaufman Test of Educational Achievement	Accelerometer	Sex, age, IQ, SES, birth weight, diagnosis of attention deficit hyperactivity disorder and CRF.	No significant associations were found between MVPA and AA.§
Resaland <i>et al</i> ^{35†}	Intervention (7-month cluster RCT) Norway, 10.2 y, boys and girls, n=596	Standardised Norwegian national tests	Accelerometer	Sex, SES, PA and AA at baseline.	No significant overall effect of the intervention (increasing 165 min/week of PA) on AA.§ There was a significant effect on numeracy among children who initially performed the poorest.‡

†Study of strong quality.

‡The symbol means that in general there is a positive correlation/association between objective physical activity and academic achievement.

§The symbol means that in general there is no correlation/association between objective physical activity and academic achievement.

¶The symbol means that in general there is a negative correlation/association between objective physical activity and academic achievement.

AA, academic achievement; BMI, body mass index; CRF, cardiorespiratory fitness; LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity; SES, socioeconomic status; VPA, vigorous physical activity; y, years.

In the three studies performed with children under 10 years old,^{17 29 32} no significant association was found between physical activity and academic achievement.

Self-report physical activity and academic achievement

Studies reporting the relationship between self-reported physical activity and academic achievement are presented in [table 3](#). Twelve of the 18 studies that reported positive associations

between physical activity and academic achievement included data from several different countries, with sample sizes ranging from 277 to 861.^{33 36–46} Of these 12 studies, three were longitudinal, and physical activity was prospectively associated with academic achievement.^{39 42 44} However, 5 of the 18 studies, two of which had weak methodological quality, did not observe any association.^{16 47–50} Nonetheless, in an interventional study, about 50 additional minutes devoted to physical activity per week,

Table 3 Description of the studies reporting the relationship between self-reported PA and AA in children and adolescents

Source and study quality	Study design and sample characteristics (country, age range/mean, grade, sex, n)	Outcome measured	PA measure	Adjustments for confounders	Main results
Daley and Ryan 2000 ^{48*}	Cross-sectional UK, 13–16 y, grades 8–11, boys and girls, n=232	School grades	PA Participation Questionnaire		Overall, no significant correlations were found between PA and AA. However, weak negative correlations were found between total PA and English scores for those aged 13, 14 and 16 years.†
Dwyer <i>et al</i> ^{37‡}	Cross-sectional Australia, 7–15 y, boys and girls, n=7962	School grades	Questionnaire	Age, school type, region, % body fat, time of sleep, ate before school, musical train and parental exercise.	More active students had better AA. The association between total PA (minutes of weekly PA) and AA were weak in girls.§
Yu <i>et al</i> ^{50*}	Cross-sectional China, 10.4 y, grades 1–4, boys and girls, n=333	School grades	PAQ-C		There was no relationship between PA level and AA.†
Ahamed <i>et al</i> ^{47‡}	Intervention (16-month cluster RCT) Canada, 10.2 y, grades 4–5, boys and girls, n=287	Canadian Achievement Test	PAQ-C	Baseline evaluate AA.	Additional 10–15 min of school time devoted to PA did not compromise AA.†
Stevens <i>et al</i> ^{42¶}	Longitudinal (5-year period) USA, grade 5, boys and girls, n=6482	Standardised test scores	Questionnaire	SES.	PA was significantly and positively related to both mathematics and reading achievement in boys and girls.§
Kristjánsson <i>et al</i> ^{46‡}	Cross-sectional Iceland, 14–15 y, grades 9–10, boys and girls, n=6345	School grades	Questionnaire	Sex, family structure, parental education and absenteeism	Although the correlation was weak, increased PA levels was positively correlated with AA.§
Edwards <i>et al</i> ^{38‡}	Cross-sectional USA, 11–13 y, boys and girls, n=694	Measures of academic progress	Questionnaire	Sex, meals, fitness measures and BMI.	Higher measures of academic progress math scores were associated with VPA and sport teams participation.§
Morales <i>et al</i> ^{41¶}	Cross-sectional Spain, 14.7 y, boys and girls, n=284	School grades	IPAQ		There was a linear relationship between MVPA and AA. There is a trend to stronger correlation when modelling the relationship with a quadratic equation.§
So ^{51‡}	Cross-sectional South Korea, 15.1 y, grades 7–12, boys and girls, n=75 066	School grades	Questionnaire	Age, BMI, the parents' education level and SES.	VPA was positively correlated with AA in boys, and MPA was positively correlated with AA in both boys and girls.§ However, undertaken ≥5 times/week, VPA in boys and strengthening exercises in both boys and girls were negatively correlated with AA.**
Syväoja <i>et al</i> ^{33‡}	Cross-sectional Finland, 12.2 y, grades 5–6, boys and girls, n=277	School grades	HBSC	Sex, children's learning difficulties, highest level of parental education and amount of sleep.	PA was directly associated with AA. MVPA had an inverse U-shaped curvilinear association with grade point average.§
Burrows <i>et al</i> ^{36‡}	Cross-sectional Chile, 12.9 y, grades 5–9, boys and girls, n=1271	System for the Assessment of Educational Quality	Questionnaire	Sex, SES and student's learning experience	Those reporting ≤2 hours/week of PA had significantly lower performance in language, maths and science, than those reporting ≥4 hours.§
Haapala <i>et al</i> ^{39‡}	Longitudinal (5-year period) Finland, 7.7 y, grades 1–3, boys and girls, n=186	Nationally normed reading achievement test battery	PANIC-PAQ	Sex, age, parental education and the age, sex, parental education and study group.	Total PA and physically active school transportation were related to better academic skills.§
Maureira Cid <i>et al</i> ⁴⁰	Cross-sectional Chile, 15.6 y, grades 9–12, boys and girls, n=309	School grades	Questionnaire		There was a significant relationship between the number of weekdays of PA and performance in mathematics, history and sciences.§

Continued

Review

Table 3 Continued

Source and study quality	Study design and sample characteristics (country, age range/mean, grade, sex, n)	Outcome measured	PA measure	Adjustments for confounders	Main results
Jaakkola <i>et al</i> ^{16‡}	Longitudinal (3-year period) Finland, 13.1 y, grade 7, boys and girls, n=325	School grades	HBSC		There was a significant longitudinal weak association between fundamental movement skills and AA. However, self-reported PA engagement was not prospectively related to AA.†
Zhang <i>et al</i> ^{43‡}	Cross-sectional China, 10.3 y, grade 5, boys and girls, n=2225	School grades	IPAQ	Sex, age, household income, family structure, parents' educational attainment, participation in extracurricular activities and health status.	Minimal intensity PA (eg, walking) was positively associated with AA scores. After controlling the analyses for school fixed effects, MPA and VPA were not associated with AA.§
Kalantari and Esmailzadeh <i>et al</i> ^{49‡}	Cross-sectional Iran, 15.7 y, boys, n=581	School grades	PAQ-A	Age, % fat, pubertal maturation and SES.	After controlling for potential confounders, PA was not significantly correlated to AA (cumulative grade point averages).†
Kantomaa <i>et al</i> ^{93‡}	Cross-sectional Finland, 16 y, boys and girls, n=8061	School grades (based on national comparable grades of the final assessment)	Questionnaire	Mother's level of education and self-rated health.	High level of PA, with a reasonable amount of time spent in sedentary behaviour, such as media use, was associated with good AA.§
Suchert <i>et al</i> ^{44‡}	Longitudinal (1-year period) Germany, 14.1 y, boys and girls, n=1011	School grades	Questionnaire	Sex, age, type of school, AA at baseline.	Students who changed from non-compliance to compliance with PA guidelines attained better AA and a greater improvement than those meeting these guidelines neither at baseline nor at follow-up assessment.§

*Study of weak quality.

†The symbol means that in general there is no correlation/association between self-reported physical activity and academic achievement.

‡Study of strong quality.

§The symbol means that in general there is a positive correlation/association between self-reported physical activity and academic achievement.

¶Study of moderate quality.

**The symbol means that in general there is a negative correlation/association between self-reported physical activity and academic achievement.

AA, academic achievement; BMI, body mass index; HBSC, Health Behaviour in School-aged Children survey; IPAQ, International Physical Activity Questionnaire; MVPA, moderate-to-vigorous physical activity; PA, physical activity; PANIC-PAQ, Physical Activity and Nutrition in Children-Physical Activity Questionnaire; PAQ-A, Physical Activity Questionnaire-Adolescents; PAQ-C, Physical Activity Questionnaire-Children; RCT, randomised control trial; SES, socioeconomic status; VPA, vigorous physical activity; y, years.

as a result of the intervention, did not increase or compromise students' academic achievement.⁴⁷ A study performed among North Korean adolescents showed interesting results since VPA was positively correlated with academic achievement, but when undertaken ≥ 5 times/week VPA was negatively correlated with academic achievement.⁵¹

Cardiorespiratory fitness and academic achievement

The description of the included studies reporting on the relationship between cardiorespiratory fitness and academic achievement is presented in [table 4](#). Cardiorespiratory fitness has most often been measured using the Progressive Aerobic Cardiovascular Endurance Run and 1 mile test. From the 28 studies that have analysed the relationship between cardiorespiratory fitness and academic achievement,^{17 37 38 44 49 52–73} it was verified that they generally supported the beneficial effect of cardiorespiratory fitness on students' academic achievement. However, in two of the studies, a significant association between cardiorespiratory fitness and academic achievement was not observed^{56 71} after adjusting the analysis for potential confounders. In the four longitudinal studies,^{44 58 64 74} staying in the healthy cardiorespiratory fitness zone or improving cardiorespiratory fitness during the observational period was significantly related to better academic achievement, reinforcing prior research indicating that

cardiorespiratory fitness has a significant and positive relationship with academic achievement. No pattern could be identified that included students' age. It is important to highlight that none of the studies of cardiorespiratory fitness observed a detrimental relationship with academic achievement.

DISCUSSION

Overall, the findings revealed that self-reported physical activity and cardiorespiratory fitness were consistently and positively associated with academic achievement. Objectively measured physical activity was inconsistently related to academic achievement. Although the results varied, physical activity does not have a detrimental effect on academic achievement.

The positive and significant association between cardiorespiratory fitness and academic achievement was shown in all reviewed studies,^{17 37 38 49 52–67 69–74} although in two studies the relationship was only observed among girls,^{52 72} and in two others the significant effect disappeared when potential confounders were included in the analysis.^{56 71} The conclusion that cardiorespiratory fitness is associated with academic achievement was reinforced by the significant findings in the four longitudinal studies reviewed.^{44 58 64 74}

Table 4 Description of the studies reporting the relationship between CRF and AA in children and adolescents

Source and study quality	Study design and sample characteristics (country, age range/mean, grade, sex, n)	Outcome measured	CRF measure	Adjustments for confounders	Main results
Dwyer <i>et al</i> ^{37*}	Cross-sectional Australia, 7–15 y, boys and girls, n=7961	School grade	1 mile test	Age, school type, region, % body fat, time of sleep, ate before school, musical train and parental exercise.	There was a positive, but weak, relationship between CRF and AA.†
Castelli <i>et al</i> ^{73‡}	Cross-sectional USA, 9.5 y, grades 3–5, boys and girls, n=259	Illinois Standards Achievement Test	PACER	Sex, age and school.	Better CRF enhanced the likelihood of having better AA.†
Eveland-Sayers <i>et al</i> ^{72‡}	Cross-sectional USA, 9.7 y, grades 3–5, boys and girls, n=134	TerraNova Standardized Academic Achievement Test	1 mile test		A positive relationship between CRF and AA in math and language among girls was observed.† There was no significant relationship among boys.§
Wittberg <i>et al</i> ^{70-*}	Cross-sectional USA, 10.6 y, grade 5, boys and girls, n=968	The West Virginia Educational Standards Test	PACER	Sex, BMI and SES.	CRF was significantly associated with AA in reading/language, math, science and social studies.†
Welk <i>et al</i> ^{68‡}	Cross-sectional USA, grades 3–12, boys and girls, n=36 835	Texas Assessment of Knowledge and Skills	PACER	Sex, grade level, school size, minority status and SES.	Results indicated a significant relationship between CRF and AA.†
Wittberg <i>et al</i> ^{69‡}	Cross-sectional USA, grade 5, boys and girls, n=1941	The West Virginia Educational Standards Test	PACER 1 mile test	Sex, BMI, SES.	There were highly significant correlations with small to medium effect sizes for both girls' PACER and boys' 1 mile run with AA in reading, math and science.†
Du Toit <i>et al</i> ^{60¶}	Cross-sectional South Africa, 10.8 y, grades 4–6, boys and girls, n=212	School grades	PACER		It was observed a positive relationship between CRF and AA, with more significant correlations found among girls than boys, and among older boys and girls.†
Edwards <i>et al</i> ³⁸	Cross-sectional USA, 11–13 y, boys and girls, n=694	Measures of Academic Progress	PACER	Sex, BMI, PA and meal price status.	Higher mile run performance was associated with higher math scores.†
Van Dusen <i>et al</i> ^{67‡}	Cross-sectional USA, 3–11 y, boys and girls, n=2 54 743	Texas Assessment of Knowledge and Skills	PACER	Sex, grade, SES and ethnicity.	Boys and girls with better CRF had better AA in reading and math.†
Wittberg <i>et al</i> ^{74‡}	Longitudinal (2-year period) USA, 5–7 y, boys and girls, n=1725	The West Virginia Educational Standards Test	PACER		Students who stayed in the healthy CRF zone had significantly higher AA scores than did students who stayed in the needs improvement zone.†
Chen <i>et al</i> ^{58*}	Longitudinal (2-year period) Taiwan, 14.9 y, grades 7–9, boys and girls, n=669	School grades	1 mile test	Sex, SES and weight status.	Improvement in CRF was significantly related to greater AA.†
de Greeff <i>et al</i> ^{59*}	Cross-sectional Netherlands, 8.0 y, grades 2–3, boys and girls, n=544	School grades	Eurofit	Sex, age and grade.	Multilevel analysis showed positive associations between CRF and math and spelling.†
Esteban-Cornejo <i>et al</i> ^{61*}	Cross-sectional Spain, 10.2 y, boys and girls, n=2038	School grades	ALPHA	Sex, age, city, pubertal status and maternal education, other fitness variables.	CRF was associated with AA in math and language, even after adjustment for fitness and fatness indicators.†
Hansen <i>et al</i> ^{17*}	Cross-sectional USA, 7.8 y, 2–4 grades, boys and girls, n=688	Standardized Composite Academic Test	PACER	Sex, grade, race, ethnicity, mother's education, household income and BMI.	CRF had a significant quadratic association with both spelling and math achievement.†
Janak <i>et al</i> ^{62‡}	Cross-sectional USA, 3–12 y, boys and girls, n=1370632	Texas Assessment of Knowledge and Skills	PACER	Grade and SES.	Positive moderate-to-strong associations were observed for CRF AA. After adjustment for SES, the magnitude of effect for CRF and AA was small.†
Sardinha <i>et al</i> ^{63*}	Cross-sectional Portugal, 12.3 y, grade 7, boys and girls, n=1531	School grades	PACER	Sex and cohorts.	CR fit students, compared with unfit students had significantly higher odds for having high AA.†
Torrijos-Niño <i>et al</i> ^{66*}	Cross-sectional Spain, 9.5 y, boys and girls, n=893	School grades	PACER	Age, parent's education, fitness and BMI.	AA scores were positively related to CRF levels.†

Continued

Review

Table 4 Continued

Source and study quality	Study design and sample characteristics (country, age range/mean, grade, sex, n)	Outcome measured	CRF measure	Adjustments for confounders	Main results
Srikanth <i>et al</i> ^{65*}	Cross-sectional USA, 12.4 y, grades 7–8, boys and girls, n=1211	Texas Assessment of Knowledge and Skills	PACER	SES, like reading, health perception and BMI.	Regression analyses revealed that CRF was a consistent predictor of the students' AA in math and reading.†
Aguilar <i>et al</i> ^{71*}	Cross-sectional Chile, 12.1 y, grade 7, boys and girls, n=395	School grades	PACER	Age, BMI, SES, PA, parental education and screen time.	Good CRF levels was associated with high language and mean AA grades; however, after adjusting for other potential confounders, these associations disappear.†§
Bass <i>et al</i> ^{67*}	Cross-sectional USA, 13.1 y, grades 6–8, boys and girls, n=838	Illinois Standardized Achievement Test	PACER	Age and SES	Boys and girls in the CRF zone (HFZ) were more likely to pass in their math and reading tests.†
Andersen <i>et al</i> ^{63¶}	Cross-sectional Denmark, 13–15 y, boys and girls, n=1119	Standardised test (mandatory exams)	Cycle ergometer	SES and ethnicity.	Students with higher CRF perform better academically than students with lower CRF.†
Castro and Oliveira ^{54¶}	Cross-sectional Brazil, 15–18 y, boys and girls, n=326	School grades	1 mile test	Age and sex	CRF was associated with AA. Being unfit doubles the likelihood of poor AA.†
Kalantari and Esmailzadeh ^{49*}	Cross-sectional Iran, 15.7 y, boys, n=580	School grades	1 mile test	Age, adiposity, pubertal maturation and SES.	CRF is significantly correlated to better AA in the adolescent boys.†
Kao <i>et al</i> ^{55‡}	Cross-sectional USA, 10.1 y, boys and girls, n=79	California Standards Test	Graded exercise test	Age, sex, grade, SES, IQ	CRF was associated with greater mathematics performance in the category of algebraic functions.†
Olivares and García-Rubio ^{56¶}	Cross-sectional Chile, grade 8, boys and girls, n=18 746	Standardised tests	Chilean Standardized System for the Assessment of Educational Quality test	Age, sex, SES, region and type of school, fitness components	CRF was not associated with AA if fitness and other fitness components were included in the model.§
de Almeida Santana <i>et al</i> ^{62¶}	Cross-sectional Brazil, 10–13 y, grades 5–6, boys and girls, n=392	Standardised test	PACER	Absolute skinfold thickness, BMI-percentiles and SES.	CRF was associated with higher academic achievement among girls.† No significant association was found among boys.§
Sardinha <i>et al</i> ^{64*}	Longitudinal (3-year period) Portugal, 11.3 years, grades 6–7, boys and girls, n=1286	School grades	PACER	Sex, BMI z-score, AA at baseline and schools.	Consistently CRF fit and improvements in CRF were prospectively associated with better AA in languages.†
Suchert <i>et al</i> ^{44‡}	Longitudinal (1-year period) Germany, 14.1 y, boys and girls, n=1011	School grades	PACER (shuttle run test)	Sex, age, type of school, AA at baseline.	High CRF predicted higher AA.†

*Study of strong quality.

†The symbol means that in general there is a positive correlation/association between cardiorespiratory fitness and academic achievement.

‡Study of moderate quality.

§The symbol means that in general there is no correlation/association between cardiorespiratory fitness and academic achievement.

¶Study of weak quality.

AA, academic achievement; ALPHA, Assessing Levels of Physical Activity; BMI, body mass index; CRF, cardiorespiratory fitness; HFZ, healthy fitness zone; PA, physical activity; PACER, Progressive Aerobic Cardiovascular Endurance Run, which is part of Fitnessgram; SES, socioeconomic status; y, years.

Possible mechanisms for the association between cardiorespiratory fitness and academic achievement

There are several potential explanations for the association between cardiorespiratory fitness and academic achievement. First, students with better academic achievement may be better oriented for success, and therefore might attempt to achieve success in both academics and physical fitness.⁷⁵ A second category of mechanisms may relate to cardiorespiratory fitness effects neural substrates. Cardiorespiratory fitness enhances brain structure and function underlying students' concentration and memory which, in turn, could relate to academic achievement. Cardiorespiratory fitness increases the density of neuronal synapses,⁷⁶ the vasculature in the cerebral cortex and the recruitment of neural resources related to the effectiveness of adapting

to task demands and fatigue.⁴ Cardiorespiratory fitness also enhances the integrity of white matter tracts in the brain during childhood, which may be one pathway to improve the cognition.^{5 77} Furthermore, at a biochemical level, cardiorespiratory fitness may enhance the synthesis of brain-derived neurotrophic factor (BDNF), and an increase in BDNF is associated with increases in neurogenesis.^{7 78 79}

What is the association between physical activity (objective and self-reported) and academic achievement?

We found a positive association between self-reported physical activity and academic achievement in most studies,^{33 36–46 51} which extends previous findings that assessed physical activity

through self-reported questionnaires.^{13 80} However, 6 of 11 studies that objectively measured physical activity showed no relationship with academic achievement^{17 29 30 32–34} and one showed a negative relationship.¹⁹ This negative association was only observed when analyses were adjusted for potential confounders including a computed z-score from cardiorespiratory and motor fitness tests.

The studies included in this review did not account for the time of day when physical activity was performed. This is an important consideration because some of the benefits that are related to physical activity on academic achievement may be acute,⁸¹ and therefore physical activity should be performed within the school environment.⁸² This lack of consistency when using self-reported versus objectively assessed physical activity associated with academic achievement has been previously discussed.^{33 82 83} Indeed, Syväoja *et al*³³ observed that self-reported, but not objectively measured physical activity, was associated with academic achievement. There are a numerous possibilities for this inconsistency; younger children tend to overestimate their physical activity relative to objective measures.⁸⁴ Interestingly, it was previously reported that those children overestimating physical activity were also those presenting with higher academic achievement.³³

Accelerometers provide several advantages in assessing physical activity, but they are not free of limitations.⁸⁵ Accelerometers are used during a short period of time that may not fully represent the typical physical activity patterns. Also, there are limitations when assessing cycling, swimming or other activities that are not reflected in typical activity counts (eg, skill-specific activities related with agility, balance, control and coordination).^{82 84} Indeed, some activities that do not accumulate activity counts may improve motor control, and this may potentially contribute to improved academic performance via opportunities to interact with the environment and rehearse language and cognitive skills.⁸⁶ Children with better motor control performance have better academic achievement.^{86 87} This is consistent with the results that demonstrate interwoven associations between motor control and cognitive development, showing that many brain areas are involved in both motor control and cognitive processes.^{88 89}

Based on the inconsistent results observed for objective and self-reported physical activity, it is clear that the relationship between physical activity and academic achievement is not yet conclusive.^{13 80} It is necessary to reinforce that self-reported physical activity methods possess several limitations in terms of reliability and validity.⁹⁰ Self-reported physical activity may be problematic in children and adolescents because they are less time conscious than adults and tend to engage in physical activity in sporadic periods with different intensities rather than consistent patterns.⁹¹ Besides compromised reliability, the validity of measures may be affected in children and adolescents who feel compelled to respond in a socially desirable manner. Children and adolescents may have difficulties in recalling physical activity and in understanding and responding to items within the questionnaire.⁹² In addition, in some instances, self-reported physical activity measures only assess the frequency, the intensity or the duration, which limits the conclusions that may be drawn regarding its relationship with academic achievement. As a result, to report that physical activity is associated with academic achievement based mainly on self-reported physical activity should be made with caution, and the assumption that participation in physical activity positively affects academic achievement or the way that children behave and learn in school has yet to be validated.¹⁵ The present study further extends this conclusion by reviewed studies using objective and subjective measures of physical activity.

Are there differences in how physical activity influences academic performance at different ages?

Since this review included the entire spectrum of school-aged children, ranging from 6 to 18 years, which is novel compared with previous reviews,^{13 14 80} results could point to differential associations between children and adolescents. In regard to the association between objective physical activity and academic achievement, positive associations were observed with students older than 10 years,^{27 28 31 35} whereas this was not seen in younger students.^{17 29 32} Perhaps during the early years of schooling, parents' education, socioeconomic status or time devoted to studying are some of the main factors that explain the students' academic success. In general, based on this review, it is not possible to conclude any relationship with age, because none of the studies were designed to examine the effect of age and most accounted for age in their analysis.

Strengths and limitations

The main strength of this review arises from the systematisation of studies on associations with cardiorespiratory fitness and physical activity, with a further differentiation between objective and self-reported physical activity. Previous reviews^{13 80} did not differentiate between objective and self-reported physical activity. The present review included school-aged children and adolescents from 6 to 18 years, which represents the entire primary, middle and secondary education in most countries.

This review has limitations that restrict the ability to draw causal inferences. Although the studies were assessed according to their methodological quality,²⁶ they were not ranked or weighted, consequently, findings from studies with weaker quality, and smaller sample sizes were given equal weight relative to findings from studies with stronger research designs and larger sample sizes. Academic achievement was measured based on school grades or standardised tests. School grades given by teacher are subject to bias because teachers' evaluation can also reflect other constructs, such as students' behaviour. Thus, it might be difficult to compare results from school grades and standardised tests.

We could not apply our methods to any interventions studies; as most studies included were cross-sectional, we must limit our conclusions. Another limitation is the fact that some studies were adjusted for potential confounders, and others were not. Furthermore, to reinforce the evidence observed in the present study, future work should endeavour to perform meta-analytic analyses. Such meta-analyses were not possible herein, as the studies reviewed possessed a wide range of metrics and outcomes, which precluded the possibility of creating a coherent analytical strategy.

CONCLUSION

Our systematic review revealed an association between cardiorespiratory fitness and academic achievement. There was inconsistency in the results of studies that examined the association between physical activity and academic achievement; this was particularly the case when physical activity was measured by accelerometry.

What are the findings?

Studies in neuroscience have shown that physical activity and cardiorespiratory fitness are related to brain structure and function.

Review

How might it impact on clinical practice in the future?

- There is a positive relationship between cardiorespiratory fitness and academic achievement.
- The results were inconsistent regarding the relationship between objective measured physical activity and academic achievement.
- Studies reporting the relationship between self-reported physical activity and academic achievement reported positive associations between physical activity and academic achievement.

Contributors AM, DAS and LBS conceived the study, and AM and DAS developed a systematic review protocol. AM and DAS conducted the literature search and selected the studies based on the title and the abstract and extracted and coded the data from all studies. Study outcomes were summarised by AM, DAS and LBS. They wrote the initial draft of the manuscript, and CHH made significant revisions and contributions. All authors read and approved the final manuscript.

Funding DAS is supported by a scholarship from the Portuguese Foundation for Science and Technology (grant: SFRH/BPD/92462/2013).

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

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Br J Sports Med published online October 14, 2017

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